ADEPT

Hypersonic Deployable Decelerators

Adaptable, Deployable Entry Technology and Placement (ADEPT) Project

An Overview Presentation for IPPW10 EDL Short Course

Dr. Peter Gage, ADEPT Technical Lead
Paul Wercinski, Project Manager

June 15, 2013

Outline

- What is a Mechanically Deployable Decelerator?
  - Adaptable Deployable Entry and Placement Technology (ADEPT)
- ADEPT architecture Mission Infusion Strategy
- Key Development Challenges and Verification Approaches
  - Examples of activities within ADEPT project
- Demonstrating End-to-End Mission Feasibility
- Recent Publications
- Summary

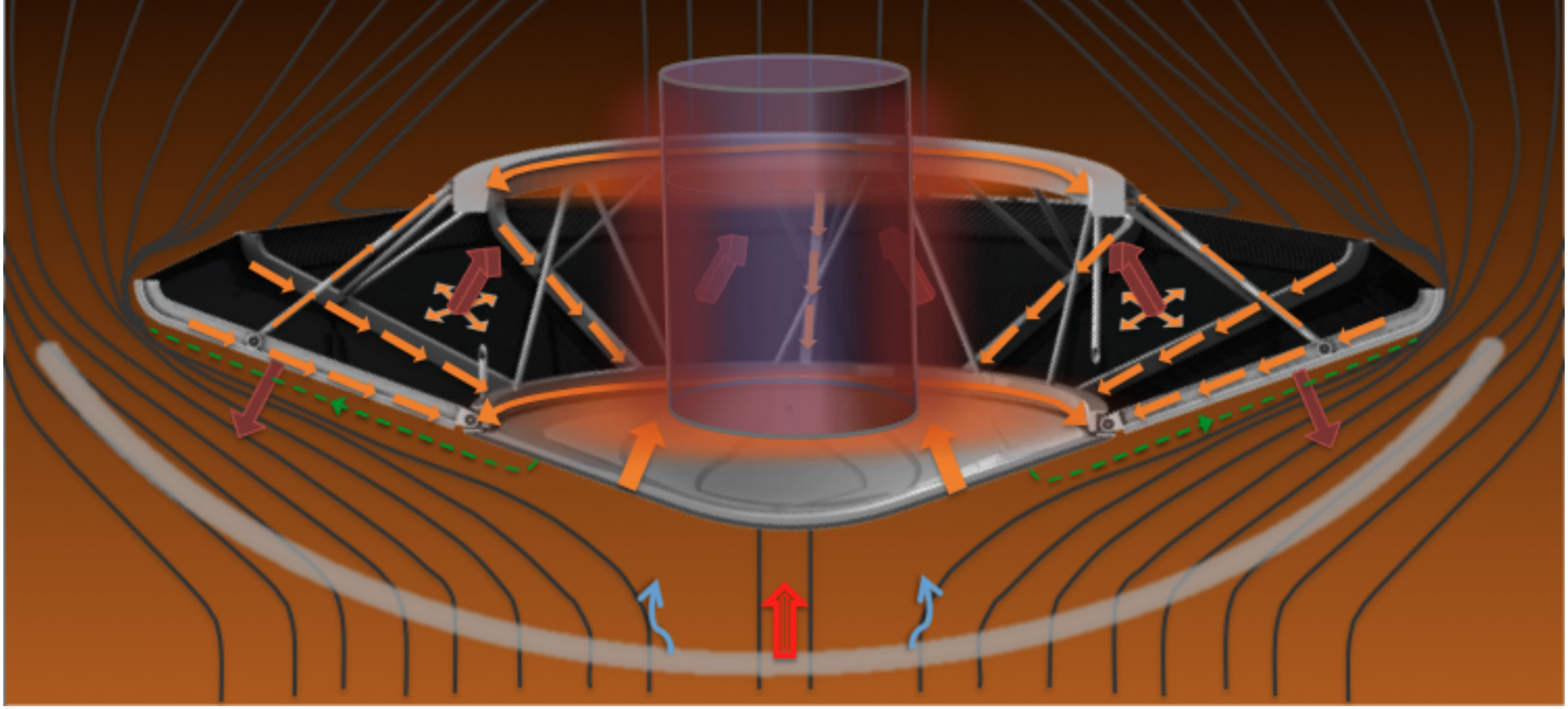
Characteristics of the Entry Problem

ADEPT

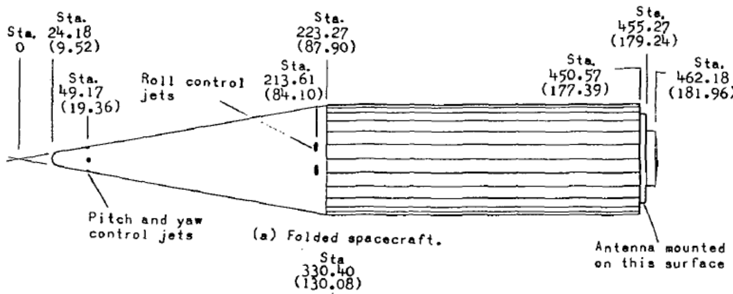
- **Entry velocity**
  - Driven by interplanetary trajectory
- **Entry angle**
  - Must be high enough to avoid skip-out
  - Affects latitude that can be reached
- **Ballistic coefficient**
  - Design choice, constrained by packaging
- **Heating rate**
  - Constrains material selection
- **Heat load**
  - Drives thermal protection thickness
- **Deceleration**
  - Drives payload structural requirements

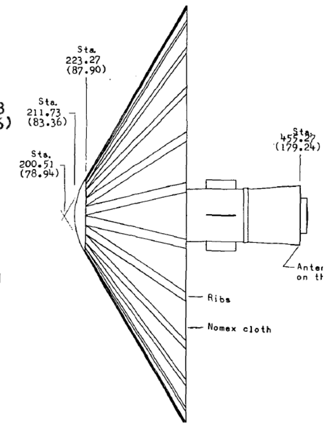
Heat Transport Mechanisms

- **Deployable design protects science payload from elevated temperatures**
  - Radiation onto payload from back of carbon cloth to payload is within the insulation capability of Multi Layer Insulation (MLI)
  - Mass estimates must account for payload thermal protection design requirements

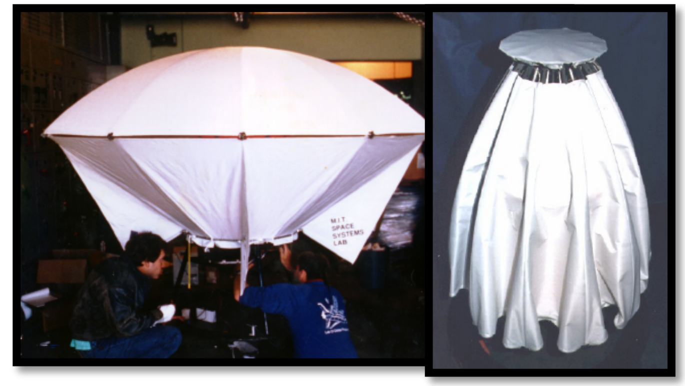


Often Proposed, Seldom Implemented

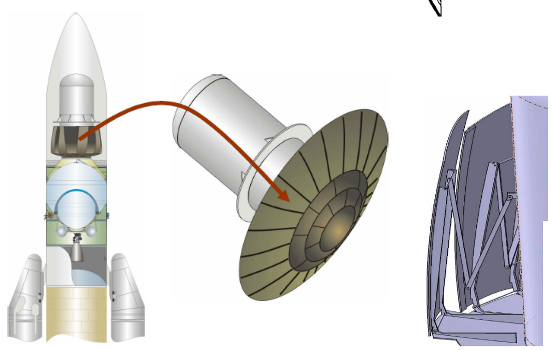




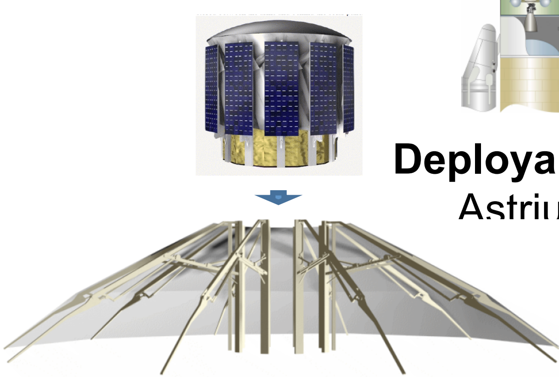
SPED, NASA LaRC, 1972



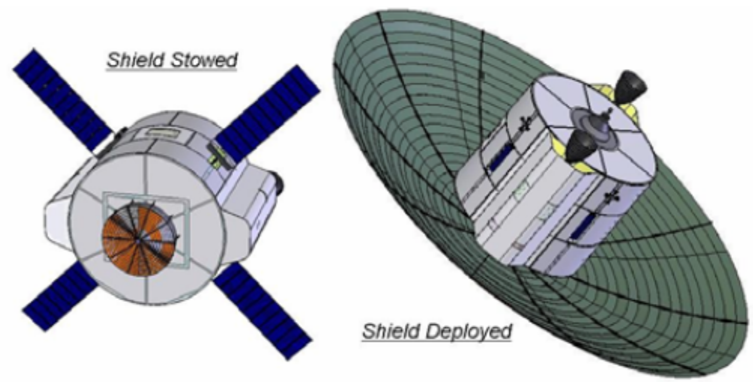
Parashield, MIT 1988



Deployable CMC Decelerator, Astrium, AIAA ADS 2003



BREM-SAT 2, U. Bremen, AIAA Small Sat 1996



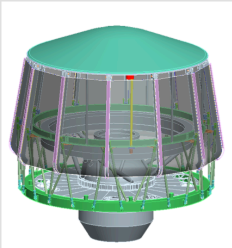
Phoenix, U. Maryland, IAC 2006

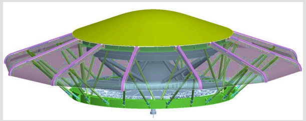
Mechanically Deployed Decelerator Overview

- **The Problem**
  - NASA needs to develop mechanically deployable aeroshell entry systems (TA09 Sect 1.1.4) to enable revolutionary capability for Science and Exploration missions beyond Earth

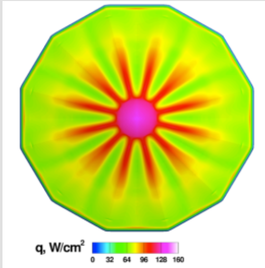
__ADEPT: (n)__ a low ballistic coefficient entry architecture (m/CdA < 50 kg/m^2) that consists of a series of deployable ribs and struts, connected with flexible 3D woven carbon cloth, which when mechanically deployed, functions as a semi-rigid aeroshell system

- **Adaptable, Deployable Entry and Placement Technology (ADEPT) Provides a Solution**
  - An innovative, mechanically deployable system achieves lower areal mass and low ballistic coefficient entry using:
    - Advances in 3-D carbon-cloth weaving that provide a TPS that doubles as aerosurface
    - Innovative mechanical design and TPS integration
  - **ADEPT Delivers!**
    - 30g max decel at Venus (300g SoA with rigid aeroshell)
    - 3D carbon fabric weave architecture that has efficient and predictable layer loss
    - Demonstrated with arc-jet testing to exceed aerothermal and structural capability required for 1000 kg payload delivery to Venus
    - Mission study conducted in collaboration with end-user science team identified enabling performance for sensitive instruments, due to low peak deceleration.

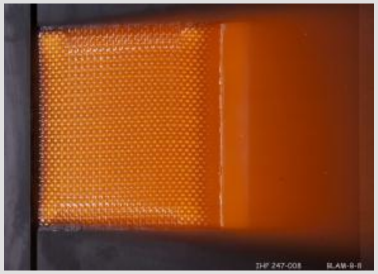




Entry Vehicle Design



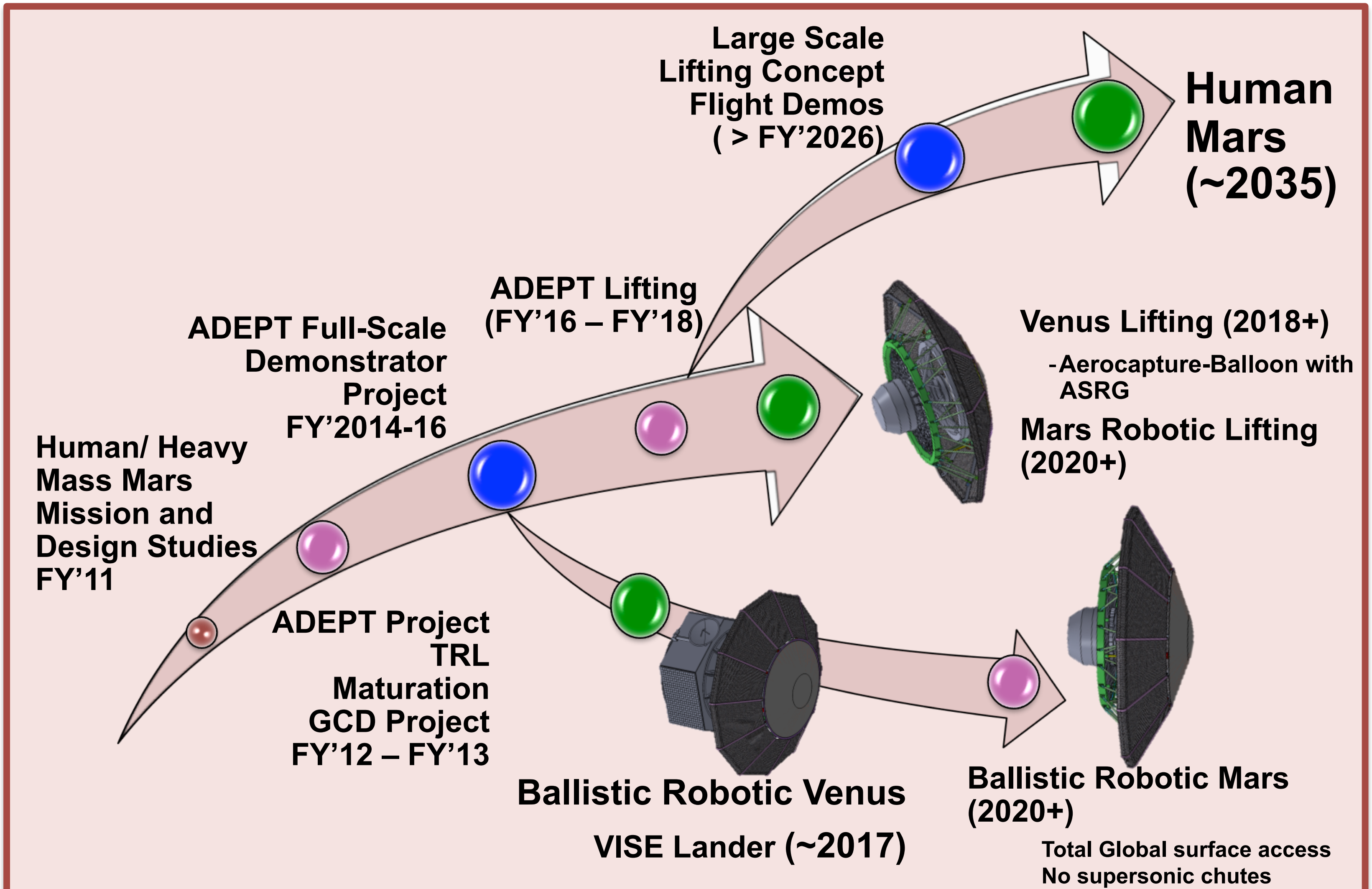
Analysis



Hardware Performance verified with Tests

ADEPT Technology Maturation and Mission Infusion Timeline

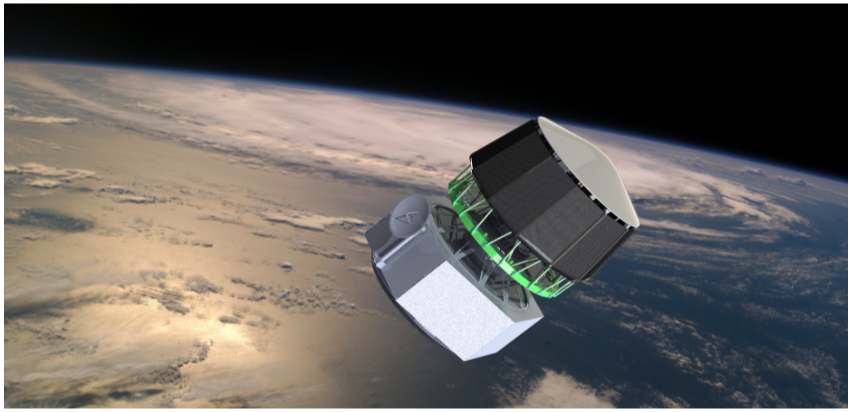
ADEPT



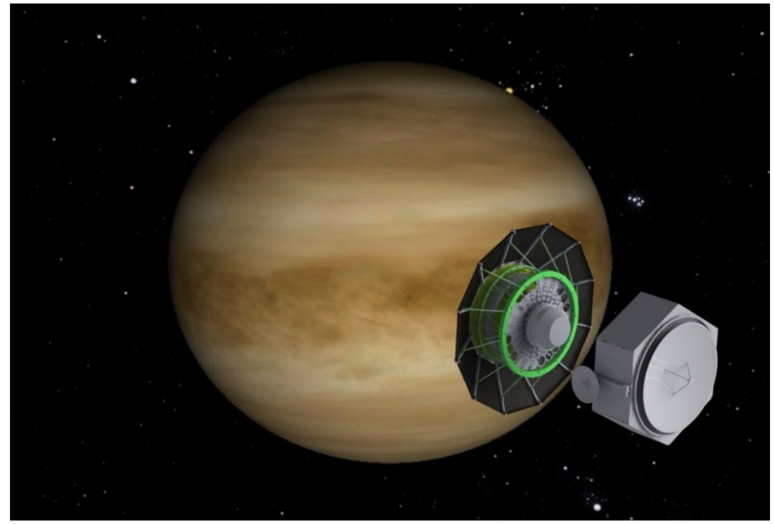
ADEPT is an Entry Architecture that delivers for Game Changing Science and Exploration Missions in the Near, Mid, and Long term

ADEPT

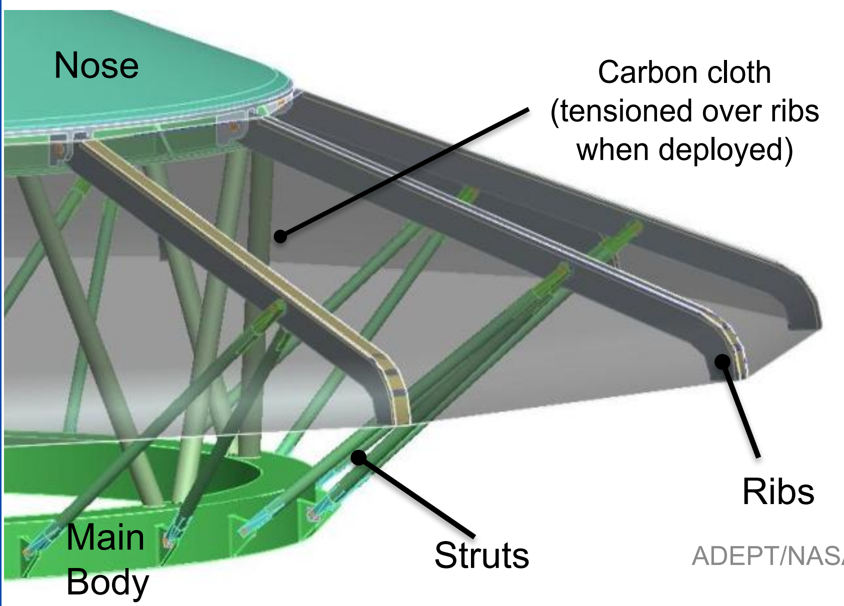
Deployable Technology and Mission Application



Earth departure



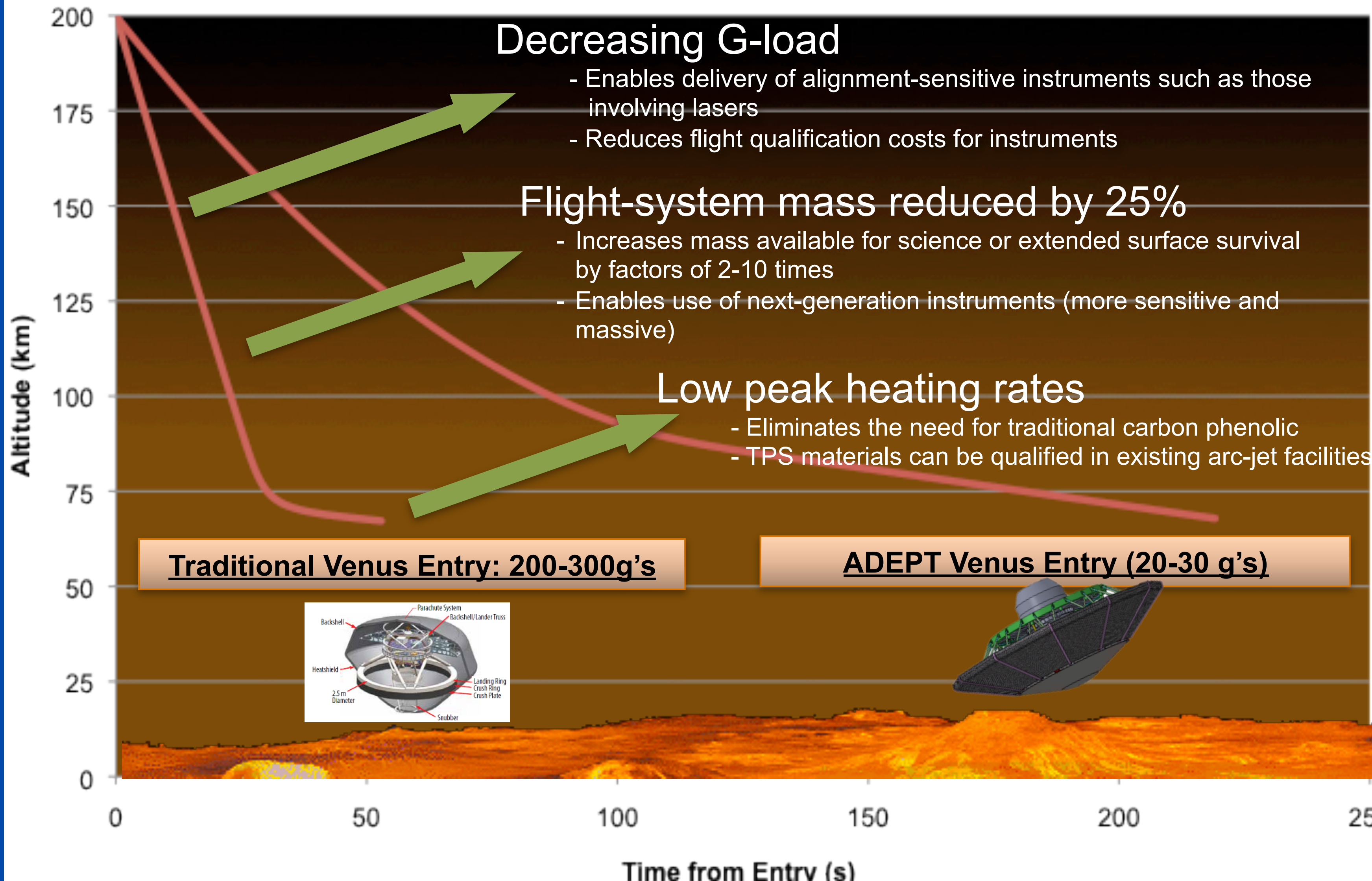
Venus Arrival



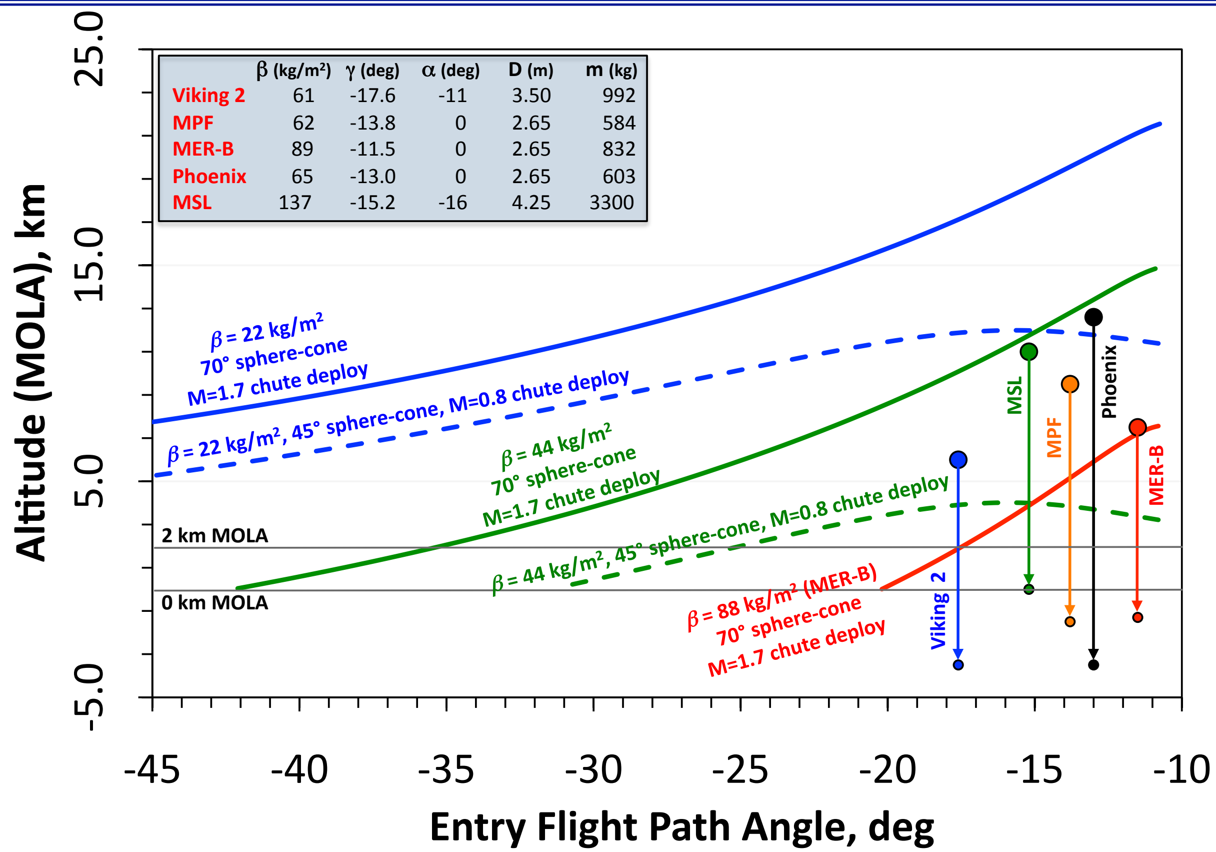
- 10.8 km/s entry, -8.25º EFPA
- Peak heating ~300 W/cm2
- Peak g-load ~30 g
- Carbon fiber yarn is woven to create a structural surface and thermal barrier
    - Top layers recede, lower layers carry structural load
    - No need for additional TPS materials
- Driven to deployment by linear actuators

High-Speed Atmospheric Entry Challenge : Achieve low-deceleration loads at Venus

ADEPT



ADEPT Enables Global Mars Access



	β (kg/m²)	γ (deg)	α (deg)	D (m)	m (kg)
Viking 2	61	-17.6	-11	3.50	992
MPF	62	-13.8	0	2.65	584
MER-B	89	-11.5	0	2.65	832
Phoenix	65	-13.0	0	2.65	603
MSL	137	-15.2	-16	4.25	3300

- ADEPT can eliminate risky EDL events for Robotic Mars
- High altitude deceleration results in benign heating and g-load's
- ADEPT can enable subsonic parachute deployment at high altitudes
  - No risky supersonic parachute needed
- Landing site elevations is not an issue – Access any site on Mars

ADEPT Requirements and KPPs

ADEPT

Level 1: Development programmatic requirements

Define **functional requirements**
Define **Interface requirements**
Identify **benefit w.r.t. conventional decelerator**
Technology development **risk list**
Perform tests to show technology capability w.r.t. mission reqts.

Level 2: Generic requirements

Generic functional requirements
Generic interface requirements
Generic benefits

Level 3: Quantitative mission-specific requirements

Location:	Venus	Mars	Earth	Mars
Mission:	VISE	Robotic/Science	L2 Return	Human
	Functional reqts. Interface reqts. Benefits	Functional reqts. Interface reqts. Benefits	Functional reqts. Interface reqts. Benefits	Functional reqts. Interface reqts. Benefits

Level 4: Test and analysis requirements

Test objectives and hardware requirements
Test environments
Analysis objectives

Prioritized by Level 1 Risk List and Cost

Key Performance Parameters (KPPs)

- Measurable engineering parameters readily understood by engineers
- Reviewed annually
- Separate threshold and goal values defined for Years 1-2
- KPP success thresholds in Year 1 and Year 2 focus on the ADEPT-VITaL application of the VISE mission

ADEPT

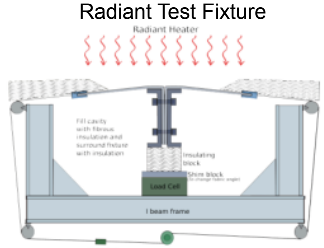
ADEPT Technology Development Challenges

Challenge Area	Description	Mitigation and Verification
Fabric Thermal Performance	Test at and above anticipated peak heating and heat load anticipated for Venus entry	Arc-jet test series in FY14 to establish performance bounds at and above expected heat rates and integrated heat loads
Fabric Interfaces	C-fabric to: 1) rib; 2) nose; 3) shoulder/ close-out	Arc-jet testing (Sprite-C) and radiant testing will establish performance and failure modes
Deployment	Deployment function and reliability testing on 2 m GTA and fullscale prototype	More relevant flight mission conditions can be replicated on ground for a range of off-nominal states
Thermostructural	Understand thermal design issues- materials selection and performance	Component level radiant tests will validate modeling tools to predict thermal and structural stress
Aerodynamic Stability	Blunt body entry vehicles in supersonic to transonic regime may be dynamically unstable	Ballistic Range Testing below Mach 3 and analysis will validate free-flight CFD codes
Integrated System	There is no end to end ground test, but the key system test is thermal vac deployment and vibe acoustic of full scale vehicle	Utilize thermal vac and vibracoustic test approaches at full scale with flight materials and relevant payload simulator
Fluid Structure Interaction	Flutter of cloth could lead to aerodynamic stability issues	Perform component level testing in relevant environment to validate FSI codes
Manufacturability	Establish manufacturing, assembly and integration at relevant scale	Relevant scale Venus aeroshell manufacturing & assembly processes will be demonstrated

BLAM Test Fixture

C-Fabric & Interface Thermal Performance

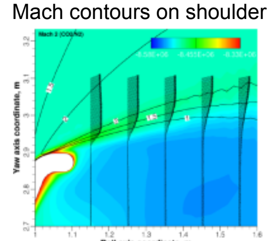
Radiant Test Fixture



Fabric/Rib Interface

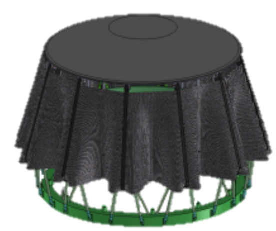
Component Thermostructural Testing

Mach contours on shoulder

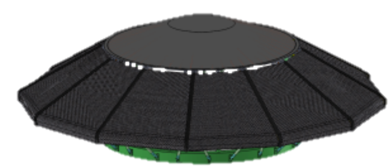


FSI modeling for wind-tunnel model design

stowed



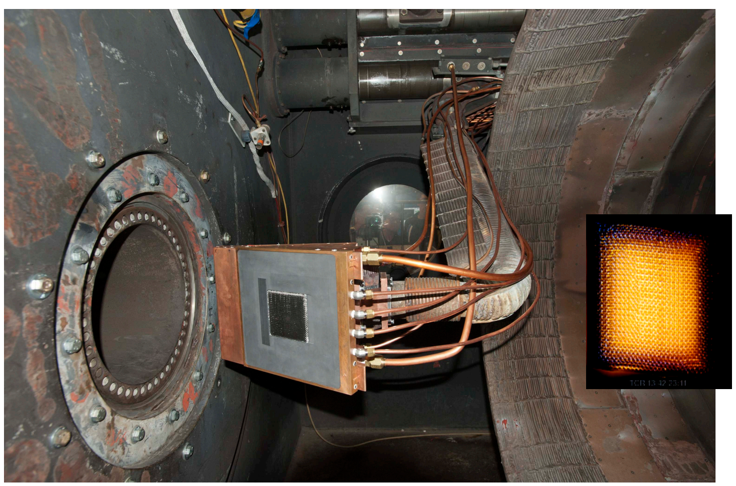
deployed

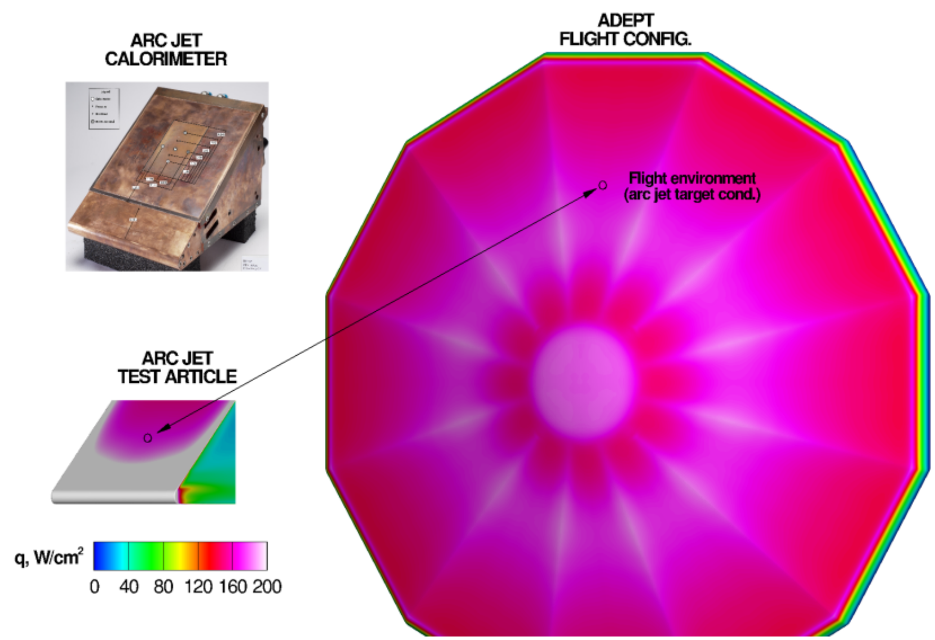


Deployment Testing

Carbon Fabric Capability Demonstration

- **Bi-axial Loaded Aerothermal Mechanical (BLAM) Test Objectives:**
  - Evaluate the carbon fabric's structural integrity under combined aerothermal and biaxial loading. Intended to be a unit test for the acreage of the ADEPT vehicle (far away from the ribs)
  - Evaluate the rate of layer loss as a function of different combined loads.
- **Test Results:**
  - Data shows that the carbon fabric is able to maintain load at temperature.
  - Biaxial load in the cloth from 188 lbs/in to 750 lbs/in has little to no impact on the rate of layer loss of the carbon fabric.
  - Flipping the warp/weft direction had little effect on the rate of layer loss of the carbon fabric.
  - Fabric tested easily withstood a heat load of 15.7 k above the 11 kJ/cm^2 expected for a Venus mission

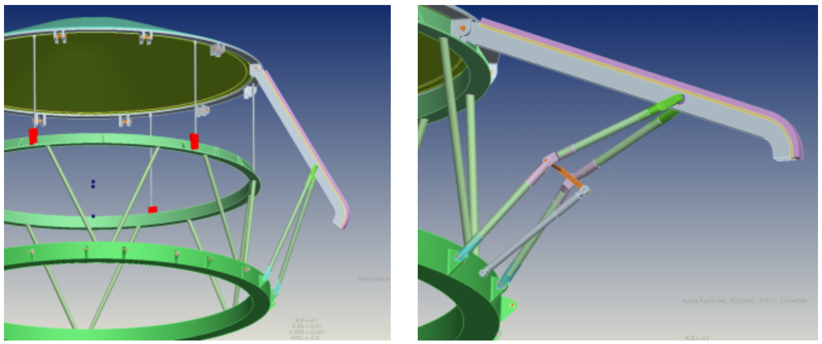




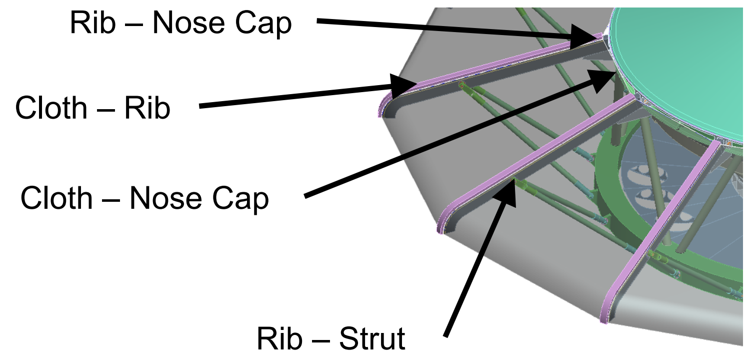
ADEPT Structures & Mechanisms Trade Study Areas

ADEPT

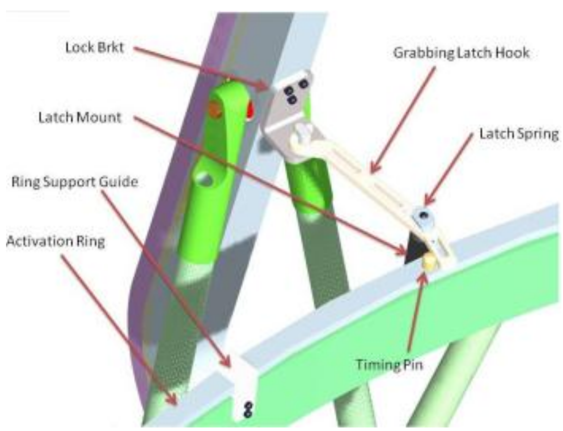
Trade studies were conducted in four categories to select subsystem configurations for ADEPT development:



Deployment Architecture & Actuation



Cloth Interfaces & Rib Configurations



Stowed Retention
(Ribs during launch)

Cloth Folding
(For launch)

Subsystem Studies

ADEPT

Trade Study	Suggested Parameters	Implementation
1. Architecture / Layout	Extending nose / folding struts / cloth supported by ribs or tension	Treated as unified trade
2. Actuation	Winch & cables / lead-screw(s) / rotary actuators / active vs. passive	
3. Cloth Attachment	Fixed to ribs / floating / number of seams	Treated as unified trade
4. Rib Construction	Closed section / split / hot vs. cold structure	
5. Tensioning	Primary deployment / secondary deployment / separate tensioners	Assume that primary deployment can deliver adequate tensioning
6. Stowed Retention	External strap / links / hinge locks / rib retention / actuation lock	Evaluated by analysis of response to launch loads
7. Cloth Folding	Out & over / S-shape / Creases	Evaluated through construction of mock-up hardware

In most cases engineering judgment from an experienced group of mechanism designers, structural analysts, and systems engineers was used to develop a feasible configuration.

Assessment relied on Figure of Merit (FOM) scoring by the team members, and vigorous discussion to challenge assumptions and achieve reasonable consensus on the configurations selected.

Insights for Ground Tests and Development Tasks

A. Deployment Testing

- A 2m diameter deployment test article is under development
- Ribs, struts, and cloth thickness scaled geometrically to evaluate function
- Actuators, control logic, sensors, latches configured to assess baseline for flight design
- Rib and nose interfaces configured to assess function of baselined options
- Substitute materials used to accelerate development and reduce cost
- Reconfigurable for testing alternate concepts

B. Thermal Testing

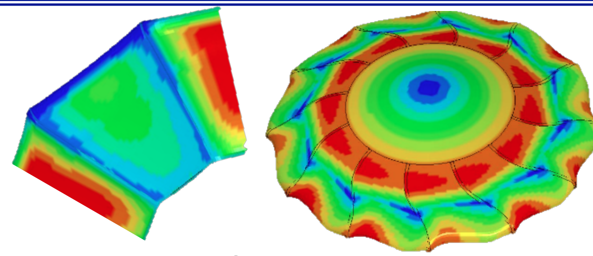
- Initial thermal testing on components and subassemblies rather than full assembly.
- Cloth, rib, and nose sections can be tested on full-scale segments
- Small radiant test facility will be used for initial tests and analysis correlation
- Follow-up testing planned for larger facility capable of a flight heating profile

C. Cloth Attachment

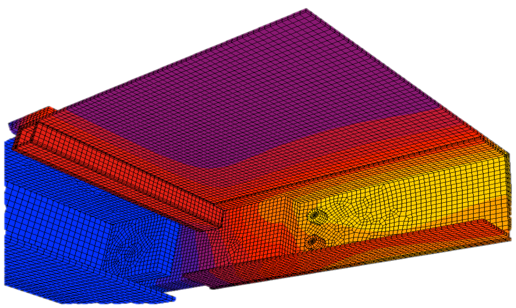
- Clamped-Split rib configuration to be tested at unit level prior to deployment testing
- Pursuing development of high-temperature seam technology for future use

ADEPT

Performance and Functional Verification with Analysis

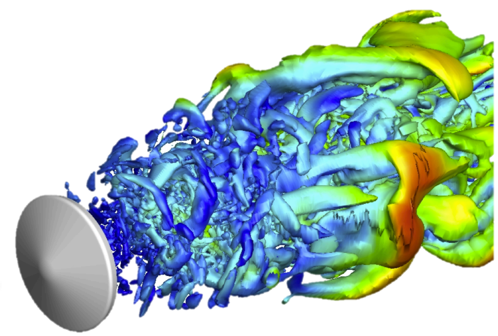


FEA/Modal Analysis
- Fabric Static Deflections
- Fabric Pretention Trades
- Structural Mode Identification

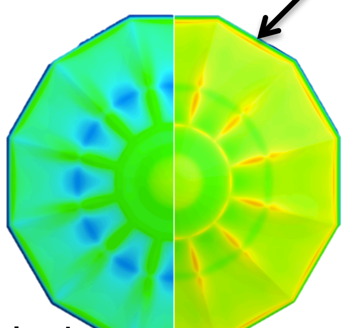


Thermostructural Analysis
- Heat Transfer Analysis
- Cloth Radiation Effects
- Thermal Stress Analysis
- Payload Protection Studies

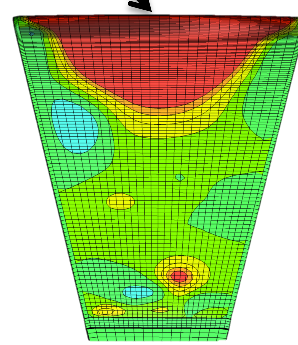
Configuration Trades
Trajectory/Mission Analyses
Static CFD



Free Flight CFD + 6DOF
- FFCFD Code Development
- Ballistic Range Test Design
- Dynamic Stability Analysis
- End-to-End Trajectory Sims



Aerothermal Analysis
- Shoulder Radius Trades
- Deflected Cloth Heating
- Local Wrinkling Effects
- Permeability Effects

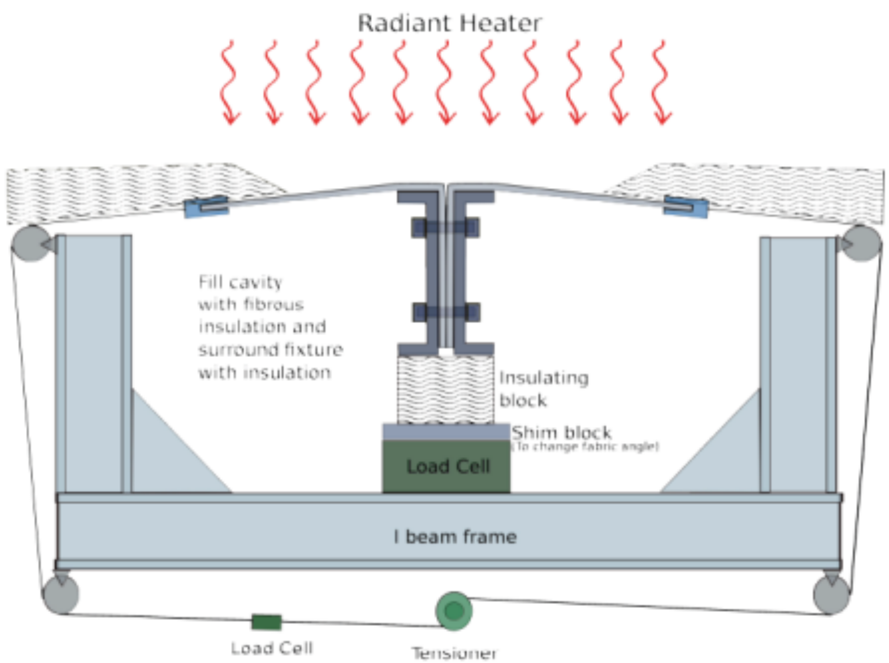


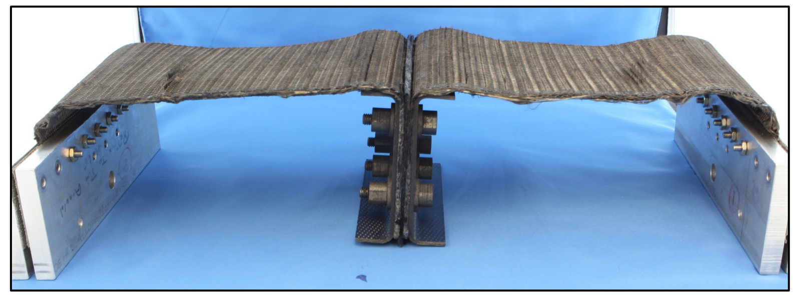
FSI Analysis
- Fabric Dynamic Deflections
- Fabric Oscillation Frequencies
- Dampening Solutions

Radiant Test Objectives

Primary Objectives

- Evaluate performance of flight-relevant structure and joints attached to carbon cloth, when carbon cloth is heated to mission-relevant temps.
- Generate temperature distribution data across the structure to anchor thermal analysis software that will be used in flight design.





Component Design and Testing

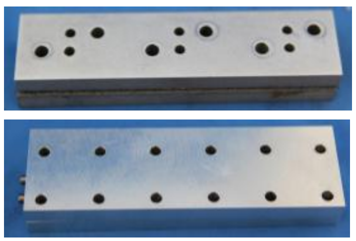
ADEPT

Design & Test- Fabric/Rib

Grip Surface S-Curve Rod/Pocket Full Noodle

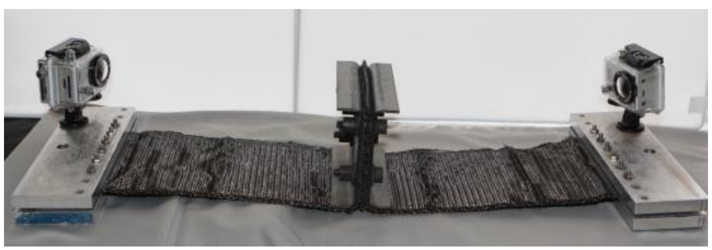
Rib Profiles

Fastener Patterns

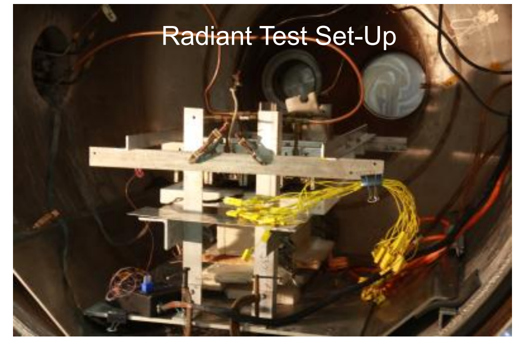


Fabric Wear & Control System Testbed

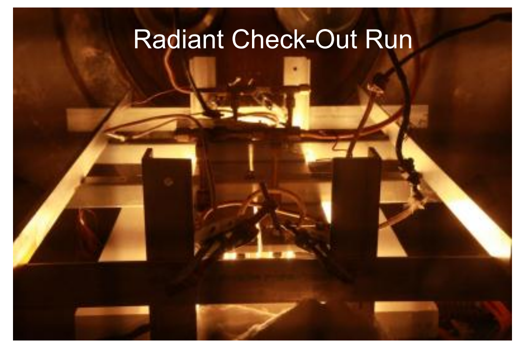
ACC/Fabric Component Testing



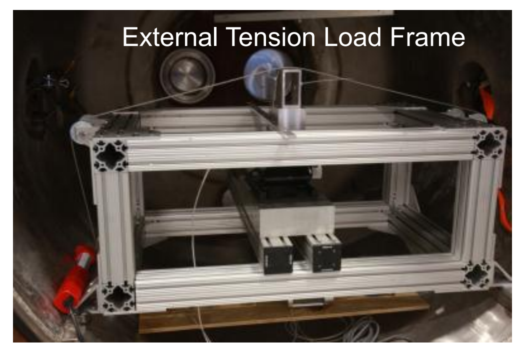
Thermostructural Testing



Radiant Test Set-Up



Radiant Check-Out Run

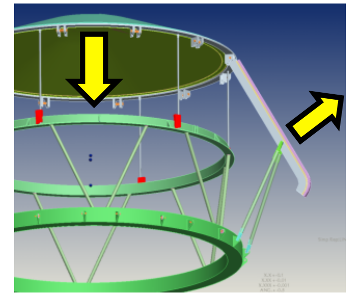


External Tension Load Frame

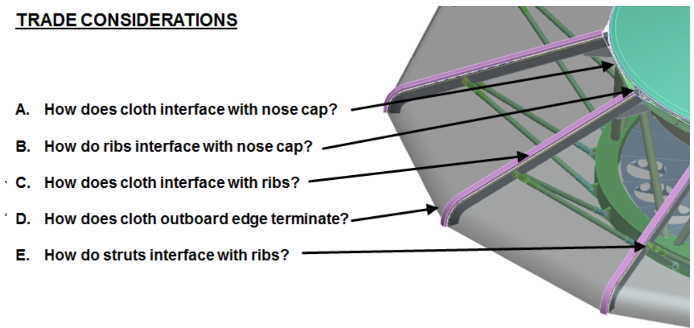
ADEPT

2m GTA Overview
A sub-scale 'stepping stone'

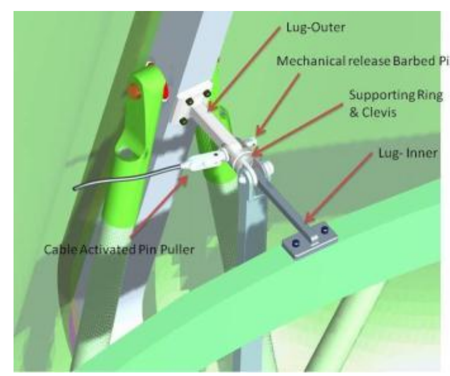
- **General configuration & motion**
  - Is the deployment motion stable & reliable with cloth attached
  - Actuation system performance & robustness to off-nominal conditions



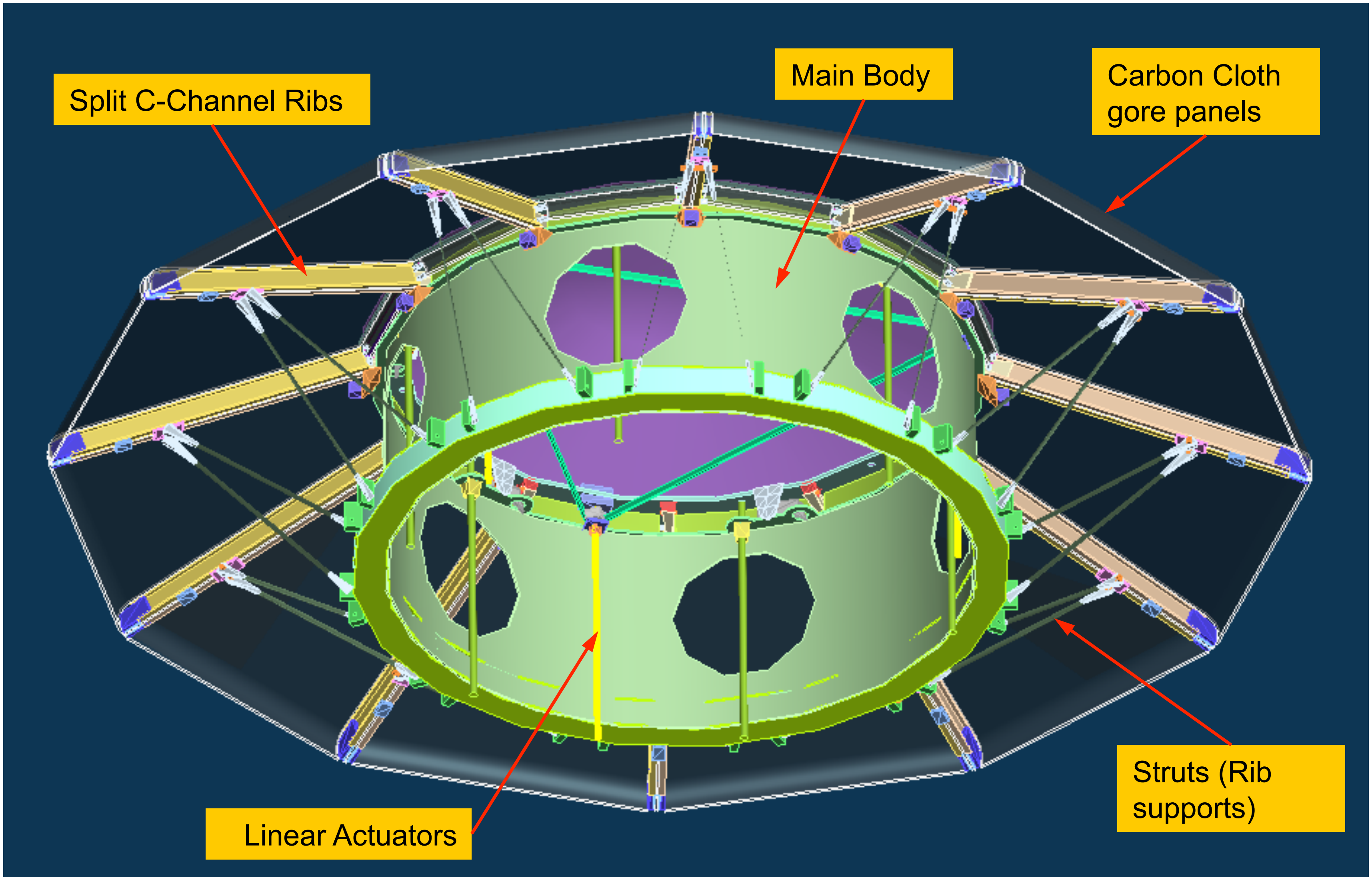
- **Cloth and rib interfaces**
  - Cloth connection to nose cap and compatibility with motion
  - Rib hinge performance (compatible with cloth)
  - Cloth-rib interface (tension capability, lack of wrinkles)
  - Cloth outboard edge interface and folding/unfolding
  - Rib-strut joint performance (compatible with cloth & motion



- **Cloth gore manufacturing & integration**
  - Do cloth integration features function as planned
  - Cloth assembly & integration procedures, tolerances, issue
- **Cloth tensioning via deployment motion**
  - Does deployment motion provide an evenly tensioned cloth
  - Does cloth deflect as expected when loaded
- **Stowed Configuration**
  - Cloth shape and ability to fold into stowed launch configuration
  - Demonstration of rib retention and release design



GTA Design Features



ADEPT Architecture Satisfies End-to-End Mission Feasibility

- **Study Objective:** ***assess the feasibility of the ADEPT concept by quantifying potential benefits for the NRC Decadal Survey's Venus In-Situ Explorer (VISE) Mission and checking for potential adverse interactions with other mission elements, such as launch and cruise.***

- **The ADEPT project chose to study the Venus Intrepid Tessera Lander (VITaL) design, a VISE lander developed by NASA GSFC for the Decadal Survey's Inner Planets Panel. Results are documented in the *ADEPT-VITaL Mission Feasibility Report*, dated 13 July 2012.**

The ADEPT-VITaL Study Addresses:

- **Mission Design Elements:**
  - **Launch vehicle**
  - **Interplanetary trajectory design / launch date**
  - **Cruise CONOPS / time of ADEPT deployment**
  - **Carrier spacecraft mods. / mass and power impacts**
  - **VITaL lander modifications and mass savings**
- **ADEPT-VITaL Vehicle Subcomponent Design:**
  - **Structures**
  - **Mechanisms**
  - **Materials**
- **Payload Separation Event**
- **Key Trade Studies:**
  - **Entry shape / trajectory**
  - **Structures and mechanisms trades**
- **Operating environments: stowed configuration**
  - **Launch vibro-acoustic**
  - **Cruise cold soak**
- **Operating environments: deployed configuration**
  - **Aerothermodynamic loads**
  - **Structural and aeroelastic loads**
  - **Aerodynamic stability and flight dynamics**

The ADEPT Team used Venus robotic as most challenging class for low ballistic coefficient decelerator applications

- Fully addressed mission feasibility
- Technology development risks identified
- Venus Mission (VISE) Stakeholder (GSFC: Glaze) supporting

ADEPT

Key Publications - ADEPT

Date	Journal or Event	Title	Author(s)
March 2013	Technical Paper - IEEE Aerospace Conference, Big Sky, MT	Venus In-Situ Explorer Mission Design Using a Mechanically Deployed Aerodynamic Decelerator	B. Smith, E. Venkatapathy, P. Wercinski, B. Yount, D. Prabhu, P. Gage, L. Glaze, C. Baker
March 2013	Technical Paper - AIAA Aerodynamic Decelerator Systems Conference, Daytona Beach, FL	Progress in Payload Separation Risk Mitigation for a Deployable Venus Heat Shield	B. Smith, B. Yount, E. Venkatapathy, E. Stern, D. Prabhu, D. Litton
March 2013	Technical Paper - AIAA Aerodynamic Decelerator Systems Conference, Daytona Beach, FL	Thermal and Structural Performance of Woven Carbon Cloth for Adaptive Deployable Entry and Placement Technology	K. Peterson, B. Yount, N. Schneider, D. Prabhu, J. Arnold, T. Squire, P. Wercinski, J. Chavez-Garcia, E. Venkatapathy
March 2013	Technical Paper - AIAA Aerodynamic Decelerator Systems Conference, Daytona Beach, FL	Structures and Mechanisms Design Concepts for Adaptive Deployable Entry Placement Technology	B. Yount, J. Arnold, P. Gage, J. Mockelman, E. Venkatapathy
March 2013	Technical Paper - AIAA Aerodynamic Decelerator Systems Conference, Daytona Beach, FL	Wake-Fabric Interactions in ADEPT-VITaL	V. Gidzak and G. Candler

Concluding Remarks

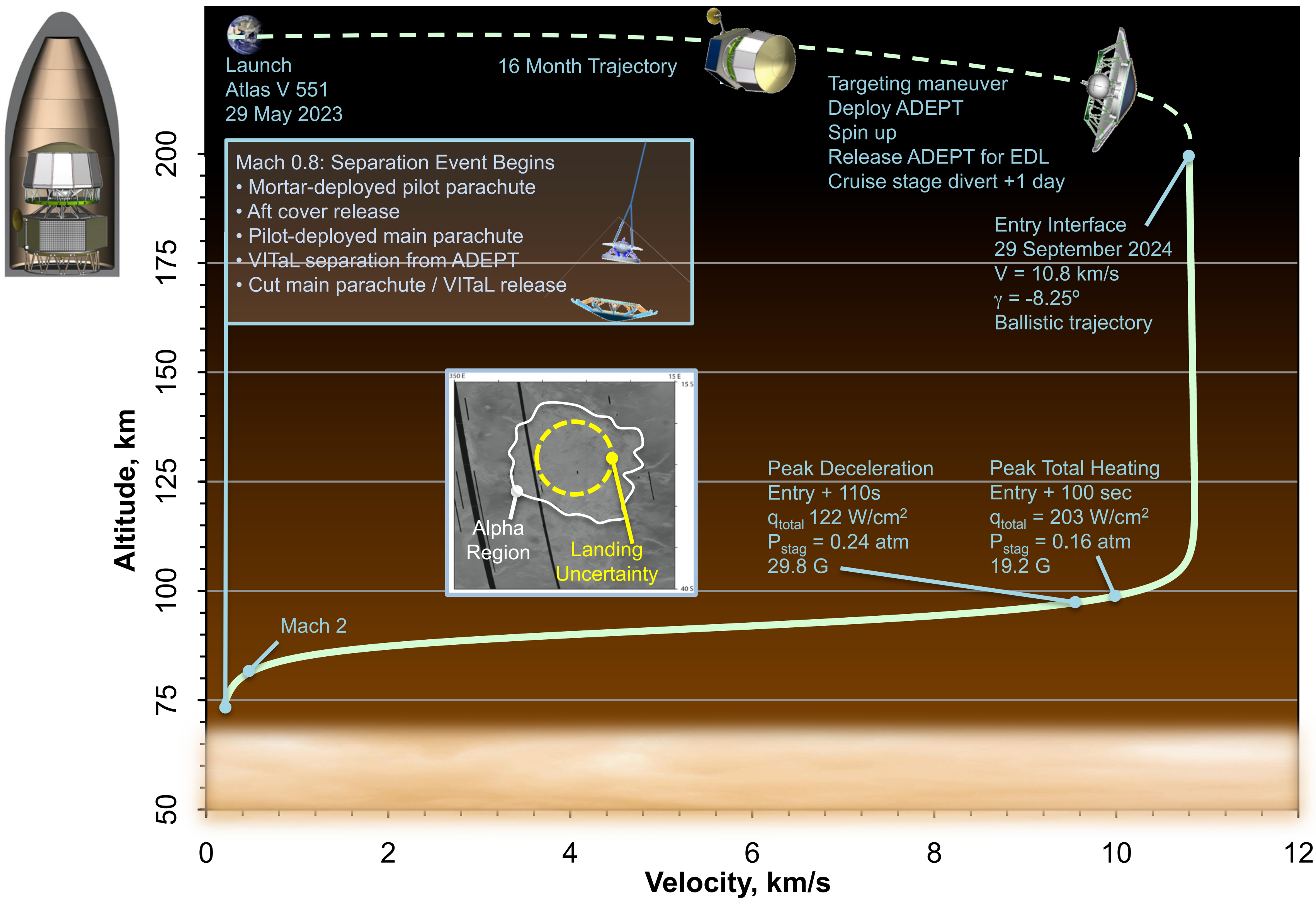
- **ADEPT, a Low Ballistic Coefficient, Mechanically Deployable Entry System Architecture is a Game Changer:**
  - Dramatically decreases severity of the entry environment conditions due to high altitude deceleration
  - Enables use of delicate and sensitive instrumentation
  - Use of flight qualified instrumentation for lower g-load at Mars and elsewhere
  - Entry mass and the launch mass are considerably reduced
- **NASA STMD GCD investment in ADEPT, mechanically deployable aeroshell technology, has broad payoff for Solar System Exploration and Science including Venus and Mars**
- **Continued Technology Maturation of ADEPT concept will**
  - Enable Venus Missions with more comprehensive science to be competitive for the next round of New Frontiers AO
  - Continue Deployable Entry Concept development for Mars robotic and eventual human exploration missions

ADEPT

Backup

ADEPT

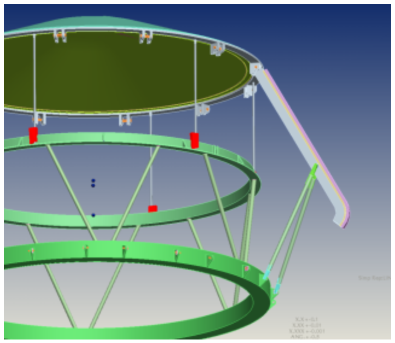
ADEPT-VITaL Mission Feasibility



ADEPT Structures & Mechanisms Trade Study Summary

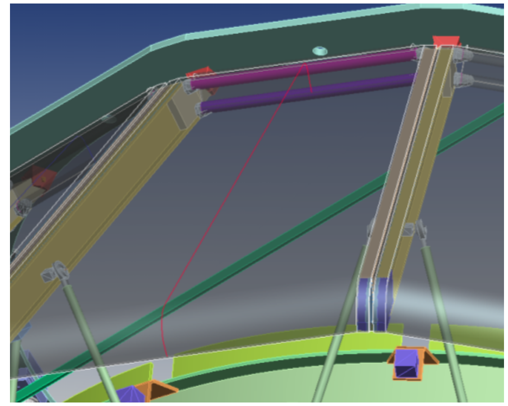
ADEPT

Preferred Options:



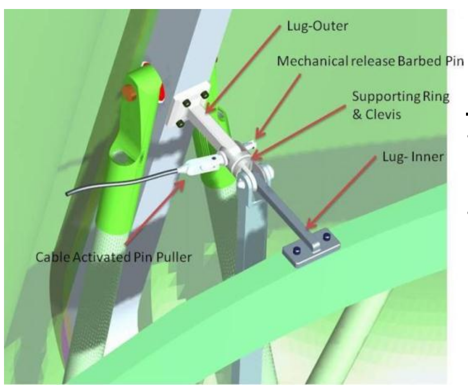
Key Factors:
- Reliability
- Robustness
- Redundancy

Extending Nose Cap & Linear Actuators



Preferred Options:
- Cloth retained via bars, clamped to nose cap via travel.
- Min offset straight ribs.
- Cloth clamped between split ribs.
- Strut pivot thru rib.

Cloth Interfaces & Rib Configurations



Key Factors:
- Analysis: survive launch environment
- Reliability

Rib retention links w/ pin puller or bolt cutter

Key Factors:
- Compatible with thick/stiff cloth
- Unfolds well
- Minimize wrinkles or damage

Simple "S" Drape

- In some cases, alternate options will also be carried forward for further development and analysis.